

Variance analysis of global CO₂ emission – A management accounting approach for decomposition study

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ABSTRACT

In the context of the present worldwide concern and desperate search for policies to curtail carbon dioxide emission, the paper aims to determine the roles of major driving forces in aggravating emission and examine the possibility of emission cut without compromising economic growth. Variance analysis method, in the line of management accounting, is used to decompose the changes in emission of 156 sample countries over the period 1993–2007. The major findings suggest that in aggregate, rising per capita GDP has been about seven times more responsible than that of population in accentuating emission; decline in energy intensity has been instrumental in offsetting nearly half of their potential effects, while inter-fuel substitution and change in emission intensities have meager roles. However, wide disparities in structural composition of energy intensity and emission intensity of fuels among countries over the period, point towards the crucial role of proper energy management in lowering emission concomitant with high economic growth. Management accounting control, particularly variance analysis, at the national level can be an effective tool in identifying the weaknesses and exploring the areas where emission reduction can be possible.

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1. Introduction

The projections relating to global emission of carbon dioxide (CO₂) and its possible linkage with the imminent climate change have sparked off considerable debates and led to the recognition of an urgent need for policy reforms. “With the global economy set to quadruple by mid-century, energy-related carbon dioxide emissions would, on current trends, more than double, putting the world onto a potentially catastrophic trajectory that could lead to temperatures more than 5 °C warmer than in pre-industrial times” (World Development Report, 2010, pp. 189).

The growing energy use in both production and consumption is likely to have serious detrimental effects on environment due to the associated CO₂ emission. Both production and consumption are reflected in the income level of a country. Thus, emission of a country is supposed to be a function of its income level. But the evidences on the precise relationship between income level and emission of a country remain inconclusive. Hamilton and Turton [1] and Shi [2] find that rising income levels are associated with a monotonically upward shift in emission. The Environmental

Kuznets Curve (EKC) postulates that as income rises, emission initially grows, reaches a maximum and finally declines to take the form of an inverted U-shaped curve. However, the EKC hypothesis is not free of contradiction in case of CO₂ emission. While the hypothesis finds support in the studies of Shafik and Bandyopadhyay [3], Grossman and Krueger [4] and Stern [5], the relationship does not hold strong in the studies of Shafik [6] and Yandle et al. [7].

However, a contradictory view suggests demographic growth as the major driving force behind increasing CO₂ emissions (Bongarrts [8]; Engelman [9]; Cramer and Cheney [10]; O'Neill et al. [11]; Cramer [12]; Shi [13]; Cole and Neumayer [14]; Onozaki [15]). More precisely, Crowley [16] points out that about 75% of emission since 1900 had been due to human influences. Dietz and Rosa [17] and York et al. [18] find that the elasticity of CO₂ emission with respect to population is close to unity, while Shi [2] conclude that on average, it is 1.28. Shi [13] using a panel data of 93 countries during 1975–1996 asserts that population effect on carbon dioxide emission depends on income levels; in the developing countries the emission-population elasticity is 1.58, while in the developed ones it is 0.83.

A number of studies contend that the emission impact of rising income is even more exacerbated when accompanied by demographic growth. Ehrlich and Holdren [19], for the first time, extend

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the view by developing the IPAT model to argue that the environmental impact (I) is the result of the number of people living in an area (P), as well as of their affluence (A) and the implemented technology (T). The recent approach to investigate the environment-development relationship is based on the decomposition technique and has been widely applied in different studies (Bruvoll and Medin [20]; Lise [21]). The studies on CO₂ emission concentrate mostly either on time series data of a specific country or region or on some selected¹ countries (Ang and Zhang [22]; Viguier [23]; Wang, Chen and Zou [24]). The decomposition analysis typically decomposes emission into scale, composition and technique effects. Scale effects are measured by income and population, composition effects refer to changes in the input or output mix and technique effects are depicted by energy intensity and emission intensity.

Within the country specific studies, there has been extensive research on the decomposition of energy intensity into sectoral composition of GDP, energy consumption per unit of output of each sector and inter-fuel substitution. While Löfgren and Muller [25] in a study of Sweden find that energy intensity has insignificant effects in reducing total energy consumption, Bhattacharyya and Ussanarassamee [26], Ma and Stern [27] and Chunlan et al. [28] in their respective studies of Thailand, China and Beijing find that the effect has considerable contribution. A common contention among these studies is that structural change of industries has the most dominating role, while inter-fuel substitution has very little contribution. However, although emission intensity has considerable role in reducing emission (World Bank [29] and Pani and Mukhopadhyay [30]), its decomposition and detail analysis has eluded the attention of researchers.

The decomposition studies have been made either on the basis of IPAT regression model or indexing methods, of which log mean divisia index (LMDI) method is the most preferred and widely used one. While the regression approach has limitations like, the presence of error terms and the inability to deal with possibilities of interdependence among the explanatory variables², the LMDI approach fails to deal with negative and zero values in the data set. In emission studies, negative values seldom occur; a more likely situation is the occurrence of zero³ values. To deal with them, Ang et al. [31] has suggested for substitution of the zeroes by small positive constants in the data set. However, the procedure could produce significant errors if there are large numbers of replacements of zeroes by the constants in the data set (Wood and Lenzen [32]).

Keeping in view the deficiencies of the previous studies, the objectives of the paper are: first, to propose an alternative decomposition method based on variance analysis, in the line of management accounting, with its advantages being that it can be expressed in the additive form and may cater to the weakness of LMDI method in handling both zero and negative values; secondly, to apply the method to examine the nature, direction and extent of linkages that tend to exist between energy-related CO₂ emission and its major driving forces in different countries; thirdly, to examine how far different countries have been successful in offsetting their emission due to 'push' effects of economic growth alongwith rising population, through 'pull' effects of improvements in emission and energy efficiencies; and finally, to examine the present role of emission intensity and its potential in curbing global emission, which has not drawn adequate attention so far.

2. Data and preliminary observations

The data source for this study is the International Energy Agency (IEA). The emission of CO₂ is expressed in million metric tons; energy consumption is expressed in terms of quadrillion British thermal unit (10¹⁵ Btu) and population is measured in millions. GDP in terms of 2005 US dollar (Purchasing Power Parity) has been calculated from data on energy intensity. The GDP figures have been derived by dividing total energy consumption by energy intensity of GDP of respective countries. Since the original database contained some missing figures on the required variables, through rejections of countries and years with missing values, we obtained a sample of 156 (out of a total 224) countries, for which complete data on the required variables were available for the period 1993–2007. Based on the regional classification of the IEA, the sample represents 41 (out of 56) countries from Africa, 32 (out of 46) from Asia & Oceania, 28 (out of 45) from Central & South America, 12 (out of 16) from Eurasia, 29 (out of 41) from Europe, 10 (out of 14) from Middle East and 4 (out of 6) from North America.

On an average, the sample represents more than 94% of the total world emission and closely follows its movement over the period (Fig. 1). As a result, we can fairly assume that the sample is representative of the population. In 1993, the world emission was 21.7 billion metric tons, which initially grew sluggishly, but since 2002, there has been a rapid growth. During the period 1993–2007, the emission grew by about 38% to reach nearly 30 billion metric tons. The country-wise⁴ data show that there exists a high dispersion in emission among the countries. Only 5% of the sample countries share about 2/3rd of the global⁵ emission in both the years, while more than 50% countries have negligible (less than 1%) contribution (Table 1). On the other hand, the top 5% emission-increasing countries account for more than 4/5th of the total increase in emission and about 3/4th of the increase in energy consumption, only to contribute a little more than half of the growth in GDP and about 2/5th of population growth during the period (Table 2). In particular, China alone accounts for nearly half of the growth in emission and 2/5th of the rise in energy consumption to contribute 1/5th of growth in GDP and support 14% growth in population. However, 18% of the countries have reduced their emission, the first 5% among them accounting for about 90% of the total reduction. The notable point is that the emission reducing countries have lowered emission equivalent to more than 9% of the total rise in global emission and nearly 4% of increase in global energy consumption, even after contributing about 12% of increase in GDP and nearly 3% of population growth. Of the top 10% emitting countries, only Russia, Germany and the United Kingdom have been able to reduce emission from their 1993 level (Fig. 2). China has substantially added to its emission, but United States, despite having the highest emission level in 1993, had much less growth than China. Although India had comparatively less absolute emission, its contribution to growth in emission is notable.

In aggregate, the correlation coefficient of the change in emission during 1993–2007 with the level of emission in 1993 is the lowest, while that with change in energy is the highest, nearly unity (Table 3). The correlation between change in emission and change in GDP is much stronger than that with change in population. At the regional level, North America had the highest correlation between emission in 1993 and the change in emission, followed by Africa, while for Eurasia and Europe there had been negative correlation. The high emitting countries in 1993 of North America

¹ However, a few studies have been made on large sample (See World Bank [29] and Pani and Mukhopadhyay [30]).

² For detailed comments on the IPAT model see Gans and Jost [33].

³ In the dataset of the present study, we find a number of zero values. See IEA database.

⁴ For country-wise data see <http://www.eia.doe.gov>.

⁵ In the remaining part of the paper, the term 'global' is referred to represent the sample total.

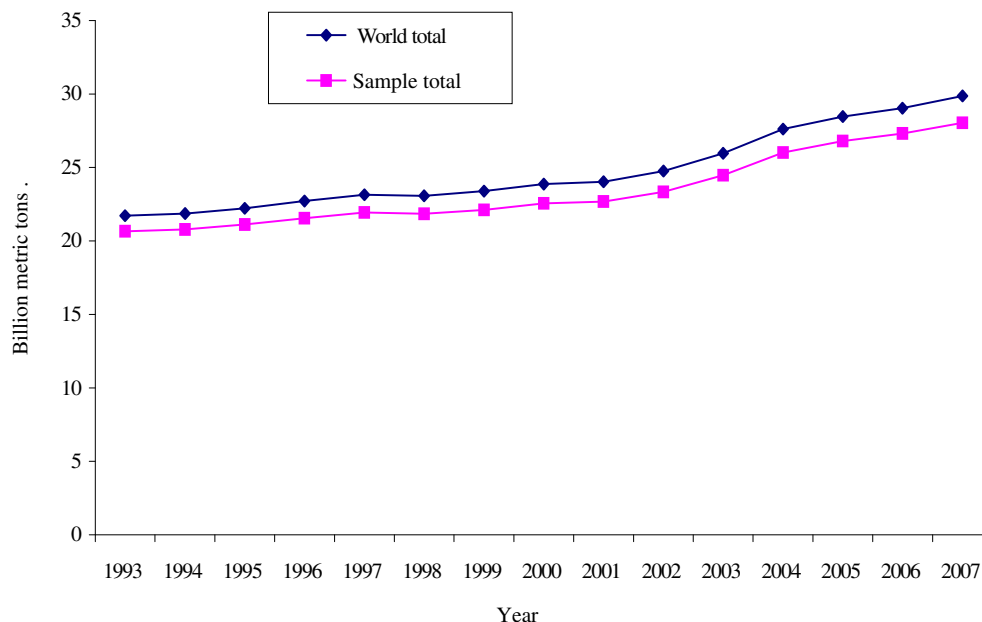


Fig. 1. Total CO₂ emission over the period 1993–2007.

Table 1
Contribution to global emission (in percentages).

Contributors (% of countries)	Contribution in 1993		Contribution in 2007	
	Lowest	Highest	Lowest	Highest
5%	0.003	64.96	0.004	65.99
10%	0.01	78.84	0.01	78.62
20%	0.04	91.08	0.05	91.58
30%	0.10	96.17	0.13	95.88
40%	0.28	98.33	0.32	98.19
50%	0.70	99.30	0.82	99.18

and Africa added even more to emission, while that of Eurasia and Europe reduced their emission. From the correlation coefficients between change in emission and that of energy, it is evident that there is a direct proportional relation between energy and emission in North America, Asia & Oceania and Middle East, indicating no or insignificant emission efficiency of energy. However, Europe and Eurasia have achieved the highest efficiency in this regard. The correlation coefficients between change in emission and that of GDP show that in North America, change in GDP was accompanied by nearly the same proportionate change in emission and in Europe, the coefficient was insignificant, while in Eurasia it was negative, indicating that only Eurasia and Europe have been successful in de-linking growths in GDP and emission. The correlations between change in emission and that of population show that the latter has significant direct impact on change in emission in

American countries but the least in Middle East and African countries.

The structural composition of fossil fuels and the resulting emission (Table 4) shows that the total use of petroleum was the highest, followed by coal and dry natural gas respectively. However, coal had the highest emission intensity, followed by petroleum and dry natural gas in the ratio of, approximately, 1.8:1.2:1. The change in emission intensities of coal and dry natural gas were insignificantly (0.11% and 0.02% respectively) positive, while that of petroleum plummeted remarkably by 3.1%. Although the quantity of use of all the sources of fuels increased, the composition of fuel mix shows that in aggregate, the rate of use of coal and dry natural gas surged by 12% and 2% respectively, while that of petroleum lowered by 9%. The rise in emission was highest due to coal, followed by petroleum and dry natural gas, and the contributions of the fuel sources to total increase in global emission were about 57%, 23% and 20% respectively.

An overview of the data brings out some crucial facts that indicate the possibility of existence of mechanisms by which emission can be arrested, despite growths in income and population. First, all countries with growing income and population do not necessarily have higher growth in emission, rather they may be associated with its reduction (e.g. Russia, Germany, the UK); secondly, emission can be reduced even with an increase in energy consumption (e.g. Hungary, Germany, Denmark); thirdly, the emission intensities of different fossil fuels vary considerably and

Table 2
Percentage contribution to changes.

Contributors (% of countries)	Highest Emission increasing countries					Lowest Emission increasing countries					Emission decreasing countries				
	Emission	Fossil fuel	Primary energy use	GDP	Population	Emission	Fossil fuel	Primary energy use	GDP	Population	Emission	Fossil fuel	Primary energy use	GDP	Population
5%	81.53	75.89	72.74	56.69	45.29	0.004	0.004	0.003	0.01	0.39	−8.14	−5.87	−3.48	9.11	−1.00
10%	95.06	90.33	87.44	67.95	55.48	0.01	0.01	0.01	0.06	0.99	−9.07	−6.50	−3.82	11.16	−0.72
18%	103.74	100.21	97.50	77.23	66.68	0.04	0.04	0.04	0.24	2.93	−9.26	−6.61	−3.84	12.09	2.63
20%	104.80	101.47	98.61	79.69	70.37	0.05	0.08	0.10	0.37	3.08					
30%	107.33	104.45	101.53	83.76	80.02	0.17	0.22	0.27	0.95	5.87					
40%	108.52	105.85	103.04	86.09	84.92	0.59	0.64	0.72	1.59	11.41					
41%	108.60	105.91	103.07	86.19	85.60	0.67	0.70	0.77	1.72	11.77					

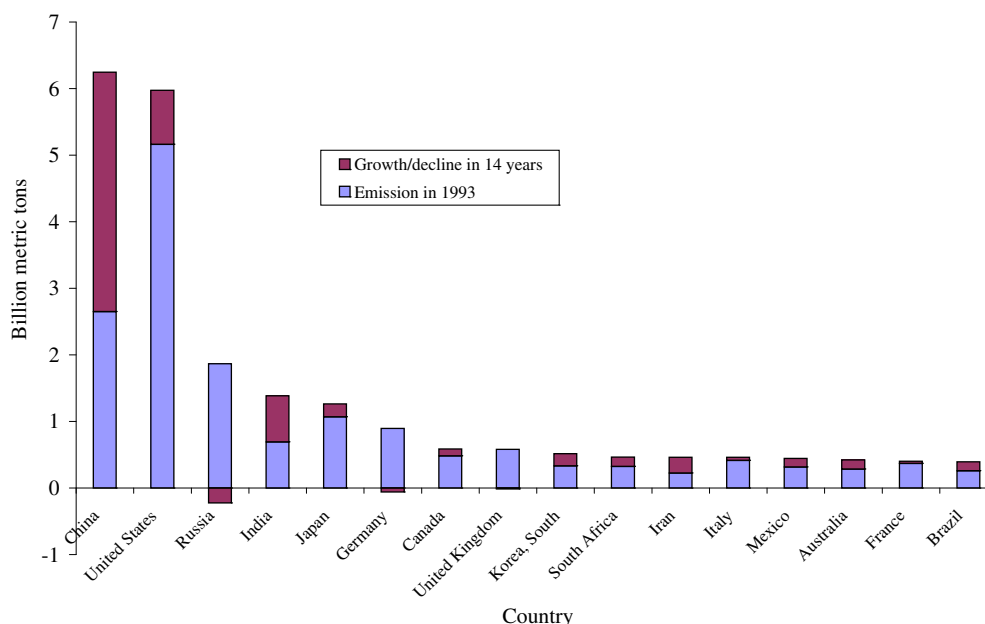


Fig. 2. Emission in 1993 and growth in emission for top 10% emitting countries.

Table 3
Region-wise Correlation Coefficients.

Region	Correlation Coefficient between change in CO ₂ and				
	1993 level emission	Change in fossil fuel	Change in primary energy use	Change in GDP	Change in Population
Africa	0.98	0.99	0.98	0.75	0.22
Asia & Oceania	0.94	1.00	1.00	0.98	0.60
Central & South America	0.96	1.00	0.99	0.95	0.91
Eurasia	-0.95	0.98	0.91	-0.83	0.88
Europe	-0.13	0.95	0.91	0.22	0.57
Middle East	0.96	1.00	1.00	0.99	0.10
North America	1.00	1.00	1.00	1.00	0.94
Aggregate	0.57	1.00	0.99	0.85	0.62

thus, their structural composition determines the emission level; fourthly, even for each fossil fuel, the emission intensity differs from country to country in the same period and from year to year in the same country, indicating the crucial role of technology and management of fuel in regulating emission. To explore the mechanisms/factors and the course of fuel management, through which, restriction of emission can be accomplished, we undertake a variance analysis of the data in the next section.

3. The model

Variance analysis technique is the most effective tool in management accounting for analysing and controlling revenue and cost variations from expectations at the corporate level. In the context of management accounting, variance represents a deviation of the actual performance from that of the standard, budgeted or targeted levels, and variance analysis enables identification of the causes behind the variations. It helps management to understand the weaknesses of the present performance and to control future results. However, the technique is also useful in other areas to determine the causal relations, where the effects can be expressed in a multiplicative form of the causes.

In the present study, with the following modifications, we apply the variance analysis method at the national level to examine

the relationship between emission and its prime determinants. First, the control variable is assumed to be energy-related CO₂ emission; secondly, the standard is assumed to be the performances in a past year (1993 in this analysis). Analogous to the practice used in management accounting in expressing total revenue as a product of price per unit and total quantity of sale, or total cost as a product of cost per unit and total quantity, following Kaya [34], we propose an identity to express emission as a product of the following five factors⁶:

$$CO_2 \equiv (CO_2/FEN) \times (FEN/PEN) \times (PEN/GDP) \times (GDP/POP) \times (POP) \quad (1)$$

where, CO₂ represents total emission, (CO₂/FEN) is emission per unit of fossil fuel consumed or the emission intensity of fossil fuel, (FEN/PEN) is the ratio of fossil fuel to primary energy, (PEN/GDP) is primary energy consumed per unit of gross domestic product (GDP) or the energy intensity of GDP, (GDP/POP) is the per capita GDP and POP is the population.

Hence, CO₂ emissions in country 'i' at time period t can be expressed as

$$CO_{2i}(t) \equiv (CO_{2i}(t)/FEN_i(t)) \times (FEN_i(t)/PEN_i(t)) \times (PEN_i(t)/GDP_i(t)) \times (GDP_i(t)/POP_i(t)) \times (POP_i(t))$$

or,

$$I_i(t) \equiv C_i(t) \cdot R_i(t) \cdot E_i(t) \cdot Y_i(t) \cdot P_i(t) \quad (2)$$

where, I_i represents total energy-related carbon dioxide emission; C_i is the emission intensity of fossil fuel; R_i is the proportion of fossil fuel in primary energy used; E_i is the energy intensity of GDP; Y_i is the per capita GDP and P_i is the population.

⁶ Although this model has been developed for national level, it can also be applied for emission analysis at the corporate level. In that case, the identity may be expressed as: CO₂ ≡ (CO₂/FEN) × (FEN/PEN) × (PEN/QNT) × (QNT), or, I(t) ≡ C(t) · R(t) · E(t) · Q(t), where, QNT and Q represent the quantity of production, and the other expressions have the same connotations as above, but at the corporate level.

Table 4

Structural composition of energy and resulting emission.

Source of Energy	Coal		Petroleum		Dry Natural Gas		Aggregate	
Year	1993	2007	1993	2007	1993	2007	1993	2007
Total emission (million mt.)	7978.37	12178.57	8548.67	10211.89	3961.74	5459.70	20488.77	27850.16
Total fossil fuel use (10 ¹⁵ Btu.)	84.64	129.06	128.25	158.10	74.99	103.32	287.88	390.47
Average emission intensity	94.26	94.37	66.66	64.59	52.83	52.84	71.17	71.32
Average rate of energy use (%)	29.40	33.05	44.55	40.49	26.05	26.46	100.00	100.00
Total change in emission		4200.20		1663.22		1497.96		7361.38

Eq. (2) implies that emission in country 'i' at a particular time period 't' depends on its total population, per capita GDP, energy intensity of GDP, ratio of fossil fuel to primary energy and emission intensity of fossil fuel at that point of time. Now, if there is a change in population, with other factors remaining constant, there must be a proportionate change in emission so that the population change may be held solely responsible for this change. Let at time period t+1, only P_i changes, other four factors remaining constant. The resulting emission is captured by say, I_{iP} which can be expressed as

$$I_{iP} = C_i(t).R_i(t).E_i(t).Y_i(t).P_i(t+1) \quad (3)$$

Now assume that alongwith change in population, GDP per capita also changes, while the other three factors remain constant. The resulting emission, say, I_{iY} is given by

$$I_{iY} = C_i(t).R_i(t).E_i(t).Y_i(t+1).P_i(t+1) \quad (4)$$

$$\begin{aligned} \text{Emission intensity variance} &= C_i(t+1).R_i(t+1).E_i(t+1).Y_i(t+1).P_i(t+1) - C_i(t).R_i(t+1).E_i(t+1).Y_i(t+1).P_i(t+1) \\ &= \Delta C_i.R_i(t+1).E_i(t+1).Y_i(t+1).P_i(t+1) \end{aligned} \quad (12)$$

$$\begin{aligned} \text{Total Emission variance, } \Delta I_i &= C_i(t+1).R_i(t+1).E_i(t+1).Y_i(t+1).P_i(t+1) - C_i(t).R_i(t).E_i(t).Y_i(t).P_i(t) \\ &= \text{eqn. (8)} + \text{eqn. (9)} + \text{eqn. (10)} + \text{eqn. (11)} + \text{eqn. (12)} \end{aligned} \quad (13)$$

In the similar way, by changing energy intensity of GDP, ratio of fossil fuel to primary energy and emission intensity of fossil fuel, one after the other, the resulting emission levels can be obtained respectively as

$$I_{iE} = C_i(t).R_i(t).E_i(t+1).Y_i(t+1).P_i(t+1) \quad (5)$$

$$I_{iR} = C_i(t).R_i(t+1).E_i(t+1).Y_i(t+1).P_i(t+1) \quad (6)$$

$$\begin{aligned} I_{iC} &= C_i(t+1).R_i(t+1).E_i(t+1).Y_i(t+1).P_i(t+1) \\ &= I_i(t+1) \end{aligned} \quad (7)$$

Eq. (7) depicts the total emission at t+1, with changes in all the factors. From the difference between Eqs. (3) and (2) we can determine the change in emission due to population change, which we call the population variance. From the difference between Eqs. (4) and (3) we can get the change in emission due to change in GDP per capita, and call it the income variance. Similarly, the energy intensity variance can be obtained by deducting (4) from (5), the substitution variance (change in emission due to change in the ratio between fossil fuel and other fuels in primary energy) can be obtained by deducting (5) from (6) and the emission intensity variance is determined by deducting (6) from (7); while the total emission variance is obtained by deducting (2) from (7). Thus,

$$\begin{aligned} \text{Population variance} &= C_i(t).R_i(t).E_i(t).Y_i(t).P_i(t+1) \\ &\quad - C_i(t).R_i(t).E_i(t).Y_i(t).P_i(t) \\ &= C_i(t).R_i(t).E_i(t).Y_i(t).\Delta P_i \end{aligned} \quad (8)$$

$$\begin{aligned} \text{Income variance} &= C_i(t).R_i(t).E_i(t).Y_i(t+1).P_i(t+1) \\ &\quad - C_i(t).R_i(t).E_i(t).Y_i(t).P_i(t+1) \\ &= C_i(t).R_i(t).E_i(t).\Delta Y_i.P_i(t+1) \end{aligned} \quad (9)$$

$$\begin{aligned} \text{Energy intensity variance} &= C_i(t).R_i(t).E_i(t+1).Y_i(t+1).P_i(t+1) \\ &\quad - C_i(t).R_i(t).E_i(t).Y_i(t+1).P_i(t+1) \\ &= C_i(t).R_i(t).\Delta E_i.Y_i(t+1).P_i(t+1) \end{aligned} \quad (10)$$

$$\begin{aligned} \text{Substitution variance} &= C_i(t).R_i(t+1).E_i(t+1).Y_i(t+1).P_i(t+1) \\ &\quad - C_i(t).R_i(t).E_i(t+1).Y_i(t+1).P_i(t+1) \\ &= C_i(t).\Delta R_i.E_i(t+1).Y_i(t+1).P_i(t+1) \end{aligned} \quad (11)$$

Hence, the method possesses additive property in the sense that the total emission variance can be expressed as the sum of variances of the above five factors. It can also deal with zero or negative values. For example, if the use of fossil fuel of a particular country becomes zero due to substitution by clean fuel, the value of I_{iR} in Eq. (6) becomes 0 and the substitution variance becomes $-[C_i(t).R_i(t).E_i(t+1).Y_i(t+1).P_i(t+1)]$. Similarly, assume a situation where the use of fossil fuel is accompanied by a reduction in the atmospheric concentration of carbon dioxide through technological innovation, indicating negative emission intensity. In that case, I_{iC} in Eq. (7) becomes negative so that the emission intensity variance becomes the sum of the values of Eq. (7) and (6), instead of their difference.

Now we turn to decompose the emission intensity. Emission intensity of a country depends on the structural composition of fossil fuel and the emission generated per unit of each fossil fuel. The sources of fossil fuel (FEN) comprise of coal (c), petroleum (p) and dry natural gas (g), so that, the total emission generated is the sum of emission from each of these fuels. Thus, emission intensity of a country can be expressed as

$$\begin{aligned} C_i &= CO_{2i}/FEN_i = (CO_{2ci} + CO_{2pi} + CO_{2gi})/FEN_i \\ &= \sum_j \left(\frac{CO_{2ji}}{FEN_i} \right) = \sum_j \left\{ \left(\frac{CO_{2ji}}{FEN_{ji}} \right) \left(\frac{FEN_{ji}}{FEN_i} \right) \right\} \text{ or,} \\ C_i &= \sum_j C_{ji}F_{ji} \end{aligned} \quad (14)$$

where $j = c, p$ and g ; C_{ji} denotes emission intensity of fuel j ; F_{ji} is the proportion of fuel j in total fossil fuel and represents the change in fuel mix.

Replacing the expression for ' C_i ' in Eq. (6), we have

$$I_{iR} = \left\{ \sum_j C_{ji}(t) F_{ji}(t) \right\} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \\ = I_{iRc} + I_{iRp} + I_{iRg}$$

where,

$$I_{iRc} = C_{ci}(t) \cdot F_{ci}(t) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (15)$$

$$I_{iRp} = C_{pi}(t) \cdot F_{pi}(t) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (16)$$

$$I_{iRg} = C_{gi}(t) \cdot F_{gi}(t) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (17)$$

Now, by changing the proportion of each fuel in total consumption, keeping their respective emission intensity unchanged, we have

$$I_{iMc} = C_{ci}(t) \cdot F_{ci}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (18)$$

$$I_{iMp} = C_{pi}(t) \cdot F_{pi}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (19)$$

$$I_{iMg} = C_{gi}(t) \cdot F_{gi}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (20)$$

When there is a change in all the fuels, at $(t+1)$ we have

$$I_{iF} = I_{iMc} + I_{iMp} + I_{iMg} = \left\{ \sum_j C_{ji}(t) F_{ji}(t+1) \right\} \\ \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (21)$$

The mix variance of coal (emission variance due to change in proportion of coal in total fossil fuel) can be determined as, Eq. (18)–Eq. (15)

$$= C_{ci}(t) \cdot \Delta F_{ci} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (22)$$

Similarly, mix variance of petroleum is given by Eq. (19) – Eq. (16)

$$= C_{pi}(t) \cdot \Delta F_{pi} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (23)$$

Mix variance of dry natural gas is given by Eq. (20) – Eq. (17)

$$= C_{gi}(t) \cdot \Delta F_{gi} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (24)$$

Total fuel mix variance can be derived as Eq. (21) – Eq. (6)

$$= \left\{ \sum_j C_{ji}(t) \Delta F_{ji} \right\} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (25)$$

Now, by changing the emission intensity (yield) of each fuel, we have

$$I_{iDc} = C_{ci}(t+1) \cdot F_{ci}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (26)$$

$$I_{iDp} = C_{pi}(t+1) \cdot F_{pi}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (27)$$

$$I_{iDg} = C_{gi}(t+1) \cdot F_{gi}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (28)$$

With the change in emission intensities of all fuels, we have

$$I_{iC} = I_{iDc} + I_{iDp} + I_{iDg} \\ = \left\{ \sum_j C_{ji}(t+1) F_{ji}(t+1) \right\} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \\ \cdot P_i(t+1) = C_i(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \\ = I_i(t+1) \text{ \{same as eqn. (7)\}}$$

The yield variance of coal (emission variance due to change in the emission intensity of coal) can be determined from Eq. (26) – Eq. (18)

$$= \Delta C_{ci} \cdot F_{ci}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (29)$$

Similarly, yield variance of petroleum is given by Eq. (27) – Eq. (19)

$$= \Delta C_{pi} \cdot F_{pi}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (30)$$

Yield variance of dry natural gas is given by Eq. (28) – Eq. (20)

$$= \Delta C_{gi} \cdot F_{gi}(t+1) \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (31)$$

Total fuel yield variance can be derived as Eq. (7) – eqn. (21)

$$= \left\{ \sum_j \Delta C_{ji} F_{ji}(t+1) \right\} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (32)$$

Thus, emission intensity variance (the sum of total fuel mix and fuel yield variances)

$$= \left\{ \sum_j C_{ji}(t) \Delta F_{ji} \right\} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \\ + \left\{ \sum_j \Delta C_{ji} F_{ji}(t+1) \right\} \cdot R_i(t+1) \cdot E_i(t+1) \cdot Y_i(t+1) \cdot P_i(t+1) \quad (33)$$

4. Decomposition results

The decomposition results (Table 5) show that in aggregate, there had been 36% increase in energy-related emission during the period 1993–2007. The increase due to rise in per capita GDP was 75% and that of population was about 11%. About 46%, 3% and 1% of these increases were offset respectively by reduction in energy intensity, emission intensity and substitution of fossil fuel by non-polluting ones. Of the sample countries, 18% (67% of Eurasia, 38% of Europe, 12% of Africa, 9% of Asia & Oceania and 4% of Central & South America) have reduced, while others have increased their emission over the period. In about 11% of the cases (67% of Eurasia, 18% of Central & South America and 14% of Europe), population variance was negative⁷; while in 13% of the countries (24% of Africa, 19% of Asia & Oceania, 10% of Middle East, 8% of Eurasia and 7% of Central & South America) the income variance was negative. 65% countries (all of Eurasia and North America, 97% of Europe, 61% of Africa, 60% of Middle East, 53% of Asia & Oceania, and 32% of Central & South America) had negative variances of energy intensity; 37% cases (55% of Europe, 50% of Eurasia, 38% of Asia & Oceania, 37% of Africa, 25% of North America, 21% of Central & South America and 10% of Middle East) had negative variances of fuel substitution;

⁷ Although in variance analysis used in management accounting, the terms 'favourable' and 'un-favourable (adverse)' are used, in this paper, we use 'positive' and 'negative' respectively for general understanding. Here, positive variance indicates an impact to increase emission and negative variance is the impact to reduce emission.

Table 5
Decomposition results of total CO₂ emission.

Region and Country	Change in total emission (ΔCO_2)	Population variance	Income Variance	Energy intensity variance	Substitution variance	Emission intensity variance	Coal mix variance	Petroleum mix variance	Dry natural gas mix variance	Total mix variance	Coal yield variance	Petroleum yield variance	Dry natural gas yield variance	Total yield variance
Africa														
Angola	5.168	1.873	11.669	-7.485	-0.774	-0.116	0	0.841	-0.610	0.231	0	-0.348	0.000	-0.347
Benin	2.198	0.483	0.200	1.453	0.064	-0.002	0	0	0	0	0	-0.002	0	-0.002
Botswana	1.651	1.197	2.357	-1.643	-0.112	-0.147	-0.562	0.421	0	-0.141	0.001	-0.007	0	-0.007
Burkina Faso	0.636	0.382	0.273	0.004	-0.007	-0.017	0	0	0	0	0	-0.017	0	-0.017
Burundi	0.030	0.191	-0.182	0.003	0.017	0.001	0	0	0	0	0	0.001	0	0.001
Cape Verde	0.188	0.017	0.161	-0.005	0	0.015	0	0	0	0	0	0.015	0	0.015
Central African Re.	0.065	0.082	-0.023	0.000	0.009	-0.003	0	0	0	0	0	-0.003	0	-0.003
Chad	0.080	0.090	0.138	-0.150	0	0.003	0	0	0	0	0	0.003	0	0.003
Comoros	0.052	0.035	-0.023	0.019	0.001	0.020	0	0	0	0	0	0.020	0	0.020
Congo (Kinshasa)	-2.088	2.267	-1.825	-0.729	-1.914	0.114	0.506	-0.357	0	0.149	-0.002	-0.034	0	-0.035
Djibouti	-0.039	0.538	-0.172	-0.298	0	-0.107	0	0	0	0	0	-0.107	0	-0.107
Egypt	65.287	29.653	56.281	-12.290	2.289	-10.646	-2.962	-24.248	19.863	-7.348	-0.301	-2.998	0.001	-3.298
Ethiopia	2.026	1.419	2.213	-0.948	-0.698	0.040	0	0	0	0	0	0.040	0	0.040
Gabon	-0.194	1.096	-0.475	-0.750	-0.066	0.000	0	0.033	-0.024	0.008	0	-0.009	0.000	-0.009
Gambia	0.119	0.126	0.030	-0.034	0	-0.003	0	0	0	0	0	-0.003	0	-0.003
Ghana	3.475	1.285	1.942	-2.447	2.903	-0.209	-0.019	0.015	0	-0.004	0	-0.205	0	-0.205
Guinea	0.197	0.447	0.316	-0.415	-0.153	0.002	0	0	0	0	0	0.002	0	0.002
Guinea Bissau	0.100	0.112	-0.079	0.068	0	-0.001	0	0	0	0	0	-0.001	0	-0.001
Kenya	5.033	2.879	0.805	0.791	0.602	-0.043	-0.435	0.336	0	-0.099	-0.001	0.057	0	0.056
Lesotho	0.080	0.025	0.077	0.163	-0.188	0.004	0	0	0	0	0	0.004	0	0.004
Liberia	0.236	0.232	0.574	-0.563	0	-0.007	0	0	0	0	0	-0.007	0	-0.007
Madagascar	1.491	0.582	0.007	0.805	0.071	0.026	-0.074	0.055	0	-0.018	0.000	0.045	0	0.044
Malawi	0.556	0.229	0.136	0.102	0.047	0.042	0.076	-0.056	0	0.020	-0.002	0.024	0	0.022
Mali	0.183	0.219	0.264	-0.306	0.004	0.002	0	0	0	0	0	0.002	0	0.002
Mauritania	-0.512	1.394	0.909	-2.609	-0.021	-0.184	-0.016	0.012	0	-0.004	0	-0.180	0	-0.180
Morocco	11.405	5.294	13.801	-4.076	-2.858	-0.756	3.994	-2.782	-0.017	1.195	-0.513	-1.438	0.000	-1.951
Niger	0.121	0.746	0.097	-0.655	-0.061	-0.004	-0.065	0.050	0	-0.014	0.000	0.009	0	0.010
Nigeria	13.141	18.668	18.357	-21.755	0.751	-2.879	-0.108	-10.341	7.701	-2.748	0.000	-0.130	0.000	-0.131
Rwanda	0.175	0.229	0.297	-0.381	0.028	0.001	0	0	0	0	0	0.001	0	0.001
Sao Tome & Principe	0.035	0.042	0.015	-0.022	0.001	-0.002	0	0	0	0	0	-0.002	0	-0.002
Seychelles	0.516	0.087	0.083	0.330	0	0.015	0	0	0	0	0	0.015	0	0.015
Sierra Leone	0.361	0.164	-0.027	0.262	0	-0.038	0	0	0	0	0	-0.038	0	-0.038
Somalia	0.208	0.305	-0.251	0.161	0	-0.007	0	0	0	0	0	-0.007	0	-0.007
South Africa	142.327	58.334	145.653	-62.490	7.465	-6.635	-6.966	-3.276	6.408	-3.834	-0.981	-1.819	-0.001	-2.801
Sudan	7.553	1.858	3.633	1.710	0.968	-0.616	0	0	0	0	0	-0.616	0	-0.616
Swaziland	0.472	0.183	0.098	0.021	0.096	0.075	0.301	-0.214	0	0.086	-0.021	0.010	0	-0.011
Togo	2.077	0.288	0.006	1.094	0.682	0.006	0	0	0	0	0	0.006	0	0.006
Tunisia	5.485	2.634	10.807	-6.731	-0.002	-1.222	-0.573	-3.158	2.673	-1.058	0	-0.163	-0.001	-0.164
Uganda	0.933	0.559	1.101	-0.727	-0.015	0.015	0	0	0	0	0	0.015	0	0.015
Zambia	0.410	0.790	0.300	-0.522	-0.100	-0.059	-0.387	0.298	0	-0.090	0.002	0.030	0	0.031
Zimbabwe	-6.301	0.675	-4.525	1.998	-4.480	0.031	0.040	-0.031	0	0.009	-0.015	0.037	0	0.022
Total	264.937	137.710	265.018	-119.048	4.549	-23.292	-7.251	-42.404	35.994	-13.661	-1.834	-7.796	-0.001	-9.631
North America														
Bermuda	0.133	0.068	0.283	-0.218	0	-0.001	0	0	0	0	0	-0.001	0	-0.001
Canada	103.054	66.347	212.192	-194.054	17.729	0.841	0.861	22.316	-18.879	4.299	0.176	-3.633	0.000	-3.457
Mexico	130.440	66.339	97.032	-29.089	7.212	-11.055	10.482	-71.066	51.137	-9.448	0.213	-1.821	0.000	-1.608
USA	811.951	814.038	1921.554	-1913.570	-39.693	29.622	-9.161	59.240	-42.758	7.321	10.809	14.698	-3.207	22.301
Total	1045.577	946.793	2231.061	-2136.931	-14.752	19.407	2.183	10.489	-10.500	2.172	11.198	9.243	-3.207	17.235
Asia & Oceania														
Afghanistan	-0.885	1.032	2.076	-3.862	-0.197	0.065	0.036	0.221	-0.185	0.072	-0.001	-0.007	0.000	-0.007
American Samoa	0.016	0.147	-0.104	-0.008	0	-0.019	0	0	0	0	0	-0.019	0	-0.019
Australia	136.860	50.745	140.541	-27.230	-27.453	0.257	9.721	-24.561	13.750	-1.090	0.041	1.306	0.000	1.347

Bangladesh	28.009	4.855	14.126	8.660	0.138	0.231	1.056	-1.624	0.605	0.037	-0.001	0.194	0.000	0.194
Bhutan	0.230	0.022	0.234	-0.041	-0.021	0.036	0.075	-0.051	0	0.024	-0.001	0.013	0	0.012
Brunei	7.260	1.094	-0.065	6.345	-0.001	-0.112	0	-2.252	1.908	-0.344	0	0.231	0.000	0.232
Burma (Myanmar)	9.965	0.812	11.237	-3.893	2.288	-0.479	0.047	-1.787	1.280	-0.461	-0.021	0.003	0.000	-0.019
Cambodia	3.426	0.159	0.912	2.588	0.355	-0.588	0	0	0	0	0	-0.588	0	-0.588
China	3598.013	292.047	7061.523	-3450.391	-122.435	-182.731	-145.649	30.402	57.869	-57.378	-28.570	-96.782	-0.001	-125.353
Fiji	1.751	0.203	0.092	1.238	0.270	-0.053	-0.145	0.112	0	-0.033	0.000	-0.020	0	-0.020
Guam	-1.287	0.692	-0.710	-1.336	0	0.066	0	0	0	0	0	0.066	0	0.066
India	693.539	184.867	887.167	-343.095	-5.911	-29.489	-49.460	18.014	13.646	-17.800	4.121	-15.809	0.000	-11.689
Japan	195.860	23.664	186.349	-54.077	44.599	-4.676	153.933	-181.054	61.830	34.710	5.474	-44.859	0.000	-39.386
Kiribati	0.019	0.009	0.005	0.006	0	-0.001	0	0	0	0	0	-0.001	0	-0.001
Korea, (N)	-44.947	6.462	-7.637	-26.745	-18.222	1.195	4.261	-3.334	0	0.927	0.196	0.071	0	0.267
Korea, (S)	184.502	29.512	309.162	-76.968	-18.445	-58.758	47.736	-94.806	52.454	5.384	0.001	-64.143	-0.001	-64.143
Laos	0.957	0.113	0.288	0.203	0.118	0.235	0.987	-0.563	0	0.424	-0.191	0.002	0	-0.189
Macau	1.102	0.459	1.728	-0.665	-0.368	-0.053	-0.008	0.006	0	-0.003	0.000	-0.050	0	-0.050
Malaysia	77.557	25.068	63.625	-20.439	2.069	7.234	25.979	-17.238	-0.985	7.756	-0.538	0.017	0.000	-0.522
Maldives	0.686	0.059	0.157	0.467	0	0.003	0	0	0	0	0	0.003	0	0.003
Nepal	2.215	0.362	0.374	1.574	-0.018	-0.078	0.551	-0.423	0	0.128	-0.002	-0.204	0	-0.206
New Zealand	8.727	5.070	14.185	-13.696	1.621	1.547	1.077	3.433	-3.246	1.264	-0.002	0.285	0.000	0.283
Pakistan	62.840	28.485	38.097	-5.064	3.062	-1.740	6.047	-14.660	7.211	-1.403	0.095	-0.433	0.000	-0.337
Papua New Guinea	1.986	1.108	-0.407	1.386	0.017	-0.117	-0.005	0.028	-0.017	0.005	0	-0.123	0.000	-0.123
Samoa	0.042	0.026	0.048	-0.027	-0.004	0.000	0	0	0	0	0	0.000	0	0.000
Solomon Islands	0.050	0.089	-0.039	0.000	0	0.000	0	0	0	0	0	0.000	0	0.000
Sri Lanka	6.634	1.033	4.066	-0.355	2.032	-0.142	0.137	-0.132	0	0.005	0.036	-0.183	0	-0.147
Taiwan	156.847	14.278	131.768	1.267	15.759	-6.225	45.163	-47.088	11.390	9.464	0.863	-16.552	0.000	-15.689
Thailand	133.251	15.442	67.660	66.488	-2.886	-13.452	16.481	-47.924	27.286	-4.157	-1.518	-7.777	0.000	-9.295
Tonga	0.090	0.026	0.007	0.050	0	0.007	0	0	0	0	0	0.007	0	0.007
Vanuatu	0.039	0.019	0.011	0.008	0	0.001	0	0	0	0	0	0.001	0	0.001
Vietnam	59.452	4.332	32.390	23.562	4.820	-5.652	-1.707	-11.614	9.405	-3.916	-0.623	-1.117	0.004	-1.736
Total	5324.806	692.291	8958.865	-3914.049	-118.810	-293.489	116.313	-396.895	254.200	-26.383	-20.641	-246.467	0.002	-267.107
Eurasia														
Armenia	4.553	-0.537	15.998	-12.232	1.238	0.086	0.166	0.653	-0.556	0.264	-0.007	-0.170	0.000	-0.178
Azerbaijan	-15.065	4.302	103.949	-121.935	-0.628	-0.754	-0.007	-3.175	2.423	-0.759	0	0.004	0.000	0.004
Belarus	-13.019	-4.170	69.199	-72.065	0.029	-6.012	-2.982	-14.178	12.131	-5.029	0.011	-0.993	0.000	-0.982
Georgia	-2.256	-0.888	9.694	-10.167	-0.594	-0.302	-0.373	0.681	-0.271	0.037	0.000	-0.339	0.000	-0.338
Kazakhstan	-48.065	-16.114	195.906	-174.235	-51.741	-1.881	4.593	-5.405	1.371	0.559	-0.914	-1.526	0.000	-2.440
Kyrgyzstan	-4.864	1.848	1.674	-5.078	-3.582	0.274	0.464	0.598	-0.701	0.361	0.004	-0.090	0.000	-0.087
Latvia	0.827	-1.066	14.763	-12.166	0.463	-1.167	-1.219	-1.662	1.986	-0.895	0.069	-0.341	0.000	-0.272
Lithuania	-0.016	-0.543	18.257	-18.469	1.468	-0.729	-0.517	-1.491	1.713	-0.295	0.488	-0.923	0.000	-0.434
Russia	-227.756	-88.271	875.677	-882.961	-49.663	-82.537	-36.808	-101.247	98.213	-39.842	-5.949	-36.747	0.000	-42.696
Tajikistan	1.659	1.442	-0.158	-1.026	0.767	0.634	0.019	2.190	-1.637	0.572	-0.001	0.063	0.000	0.061
Ukraine	-137.003	-53.417	68.877	-129.584	-19.343	-3.537	4.925	-10.269	4.890	-0.454	-0.640	-2.443	0.000	-3.082
Uzbekistan	6.443	25.928	59.264	-77.153	0.865	-2.461	-2.051	-7.694	6.856	-2.888	0.042	0.386	0.000	0.427
Total	-434.561	-131.485	1433.100	-1517.070	-120.719	-98.386	-33.791	-140.997	126.418	-48.370	-6.897	-43.120	0.000	-50.017
Central & South America														
Antigua and Barbuda	0.218	0.114	0.267	-0.169	0	0.006	0	0	0	0	0	0.006	0	0.006
Argentina	49.418	18.971	40.979	-7.788	4.946	-7.691	0.249	-22.285	17.007	-5.028	0.005	-2.667	0.000	-2.663
Aruba	0.361	0.247	0.076	0.084	0	-0.045	0	0	0	0	0	-0.045	0	-0.045
Bahamas	2.763	0.399	0.485	1.652	0	0.226	0	0	0	0	0	0.226	0	0.226
Belize	0.680	0.129	0.126	0.574	-0.122	-0.026	0	0	0	0	0	-0.026	0	-0.026
Bolivia	8.289	1.678	1.587	4.049	0.744	0.231	0	-0.914	0.751	-0.163	0	0.394	0.000	0.394
Brazil	137.142	57.287	80.184	16.993	-1.503	-15.819	-12.335	-23.295	25.839	-9.791	0.261	-6.289	0.000	-6.028
Cayman Islands	0.192	0.159	0.018	0.013	0	0.002	0	0	0	0	0	0.002	0	0.002
Chile	29.898	6.073	24.972	-5.533	4.044	0.341	2.465	-4.393	1.949	0.020	-0.025	0.345	0.000	0.320
Colombia	7.279	11.529	22.173	-19.130	-4.314	-2.979	-6.528	-0.258	3.941	-2.846	0.014	-0.147	0.000	-0.133
Cuba	-3.687	1.696	25.212	-30.225	0.169	-0.538	-0.135	-1.421	1.114	-0.441	0.005	-0.103	0.001	-0.097

(continued on next page)

Table 5 (continued)

Region and Country	Change in total emission (ΔCO_2)	Population variance	Income Variance	Energy intensity variance	Substitution variance	Emission intensity variance	Coal mix variance	Petroleum mix variance	Dry natural gas mix variance	Total mix variance	Coal yield variance	Petroleum yield variance	Dry natural gas yield variance	Total yield variance
Dominica	0.057	0.002	0.015	0.040	0.000	0.000	0	0	0	0	0	0.000	0	0.000
Ecuador	10.594	4.856	3.010	1.986	0.397	0.345	0	-0.415	0.325	-0.090	0	0.435	0.000	0.435
El Salvador	3.174	0.951	0.985	1.542	-0.261	-0.043	-0.003	0.002	0	-0.001	0.000	-0.042	0	-0.042
Grenada	0.158	-0.001	0.083	0.081	0	-0.005	0	0	0	0	0	-0.005	0	-0.005
Guyana	0.466	-0.005	0.573	-0.064	0.009	-0.047	0	0	0	0	0	-0.047	0	-0.047
Haiti	1.200	0.191	-0.137	0.772	0.356	0.017	0	0	0	0	0	0.017	0	0.017
Honduras	5.179	1.188	0.694	1.177	1.903	0.216	0.527	-0.365	0	0.162	-0.057	0.111	0	0.055
Jamaica	4.452	1.346	0.117	2.988	0.009	-0.008	-0.106	0.138	0	0.032	0.033	-0.073	0	-0.040
Netherlands Antilles	3.208	1.386	-0.260	0.663	0	1.419	0	0	0	0	0	1.419	0	1.419
Panama	2.745	3.414	9.209	-9.319	-0.427	-0.132	-0.187	0.128	0	-0.059	0.000	-0.073	0	-0.073
Peru	11.038	5.531	16.228	-9.978	0.086	-0.829	2.177	-4.381	2.070	-0.134	-0.075	-0.619	-0.001	-0.695
Saint Kitts and Nevis	0.110	-0.002	0.061	0.050	0	0.001	0	0	0	0	0	0.001	0	0.001
Saint Lucia	0.213	0.019	0.037	0.160	0	-0.004	0	0	0	0	0	-0.004	0	-0.004
Saint Vincent/Grenadines	0.122	-0.002	0.055	0.052	0.024	-0.006	0	0	0	0	0	-0.006	0	-0.006
Suriname	0.574	0.277	0.711	-0.925	0.488	0.023	0	0	0	0	0	0.023	0	0.023
Trinidad & Tobago	30.218	-0.381	25.993	4.822	0.042	-0.258	0	-3.461	2.850	-0.610	0	0.352	0.000	0.352
Venezuela	50.058	27.491	18.242	4.307	-6.352	6.369	0.736	15.945	-13.298	3.382	0.001	2.985	0.000	2.986
Total	356.118	144.544	271.696	-41.125	0.238	-19.235	-13.141	-44.975	42.549	-15.568	0.161	-3.829	0.000	-3.667
Middle East														
Bahrain	13.079	4.863	11.009	-2.794	0	0.002	0	0.637	-0.474	0.163	0	-0.161	0.000	-0.161
Iran	239.781	19.405	164.840	99.453	3.945	-47.862	-4.494	-134.029	103.120	-35.403	0.000	-12.460	0.001	-12.459
Iraq	16.452	32.754	72.794	-86.953	-0.120	-2.022	0	4.712	-3.531	1.180	0	-3.202	0.000	-3.202
Jordan	10.003	5.582	6.490	-0.693	0.051	-1.426	0	-5.700	4.306	-1.394	0	-0.029	-0.003	-0.032
Kuwait	46.958	20.537	-0.822	22.824	0.002	4.417	0	2.821	-2.152	0.668	0	3.749	-0.001	3.749
Lebanon	3.607	2.117	4.863	-3.540	0.106	0.061	0.117	-0.091	0	0.026	0.000	0.034	0	0.035
Oman	20.142	8.364	3.065	9.380	0	-0.667	0	-2.385	1.741	-0.644	0	-0.023	0.000	-0.023
Syria	13.796	18.860	6.215	-12.447	1.285	-0.115	0.003	-3.530	2.656	-0.870	0.000	0.755	0.000	0.755
United Arab Emirates	74.433	98.150	55.016	-71.326	0	-7.408	0	-19.629	13.934	-5.695	0	-1.713	0.001	-1.713
Yemen	9.417	5.600	3.613	1.077	0	-0.872	0	0	0	0	0	-0.872	0	-0.872
Total	447.670	216.233	327.083	-45.020	5.267	-55.893	-4.374	-157.194	119.599	-41.969	0.000	-13.922	-0.002	-13.924
Europe														
Albania	1.448	0.236	3.688	-2.707	0.655	-0.423	-0.836	0.696	-0.074	-0.214	-0.001	-0.208	0.000	-0.209
Austria	13.955	1.546	21.161	-10.094	2.290	-0.948	1.316	-0.464	-0.344	0.507	0.279	-1.734	0.000	-1.455
Belgium	17.190	3.834	44.571	-21.019	0.525	-10.720	-21.862	5.633	8.246	-7.983	2.114	-4.851	0.000	-2.737
Bosnia and Herzegovina	5.087	2.309	70.744	-68.558	1.108	-0.516	1.574	-0.582	-0.424	0.568	-0.903	-0.181	0.000	-1.084
Bulgaria	-0.088	-6.932	30.916	-25.107	1.009	0.027	6.062	-0.551	-2.950	2.561	0.067	-2.601	0.000	-2.534
Croatia	6.298	0.027	11.050	-4.492	-1.269	0.982	0.121	2.887	-2.244	0.764	0.429	-0.211	0.000	0.218
Czech Republic	-13.889	-1.113	70.393	-67.919	-7.375	-7.875	-18.056	8.376	3.302	-6.378	0.047	-1.543	0.000	-1.497
Denmark	-2.275	3.181	19.061	-19.801	-5.718	1.003	-6.571	0.287	4.177	-2.106	3.187	-0.078	0.000	3.109
Finland	5.035	1.802	34.216	-27.411	-1.975	-1.597	0.005	-2.809	2.179	-0.625	-0.985	0.013	0.000	-0.972
France	32.443	28.149	105.691	-80.962	-7.864	-12.570	-11.849	-16.375	20.245	-7.978	-2.637	-1.955	0.000	-4.592
Germany	-62.887	14.010	218.028	-227.175	-28.946	-38.804	-19.850	-49.253	50.547	-18.555	0.324	-20.573	0.000	-20.249
Greece	26.136	2.604	51.573	-23.599	0.988	-5.430	-11.179	-1.863	7.525	-5.518	0.128	-0.045	0.006	0.088
Hungary	-2.285	-2.135	40.779	-33.760	-1.306	-5.863	-5.035	-1.921	4.311	-2.645	-0.065	-3.154	0.000	-3.219
Ireland	16.364	4.187	47.224	-30.270	-2.223	-2.554	-6.798	2.775	1.800	-2.222	-0.329	-0.003	0.000	-0.332
Italy	48.870	8.144	95.537	-37.245	0.763	-18.329	16.712	-76.250	48.612	-10.927	-0.083	-7.320	0.001	-7.402
Luxembourg	0.244	2.467	8.201	-8.038	0.195	-2.581	-5.597	1.749	1.413	-2.434	-0.055	-0.091	0.000	-0.146
Macedonia	-1.162	0.712	2.516	-3.889	-0.711	0.210	0.116	0.351	-0.326	0.141	0.084	-0.014	0.000	0.069
Malta	0.321	0.239	1.388	-1.214	0.000	-0.092	-0.734	0.583	0	-0.151	0.000	0.059	0	0.059
Netherlands	58.158	18.893	88.203	-73.939	-7.394	32.395	-2.307	17.026	-12.548	2.170	23.920	6.305	0.000	30.225
Norway	7.600	2.457	13.998	-12.388	3.839	-0.306	-1.037	-2.153	2.312	-0.878	0.031	0.542	0.000	0.573
Poland	-43.913	0.448	321.104	-326.484	-6.310	-32.671	-61.138	32.441	10.593	-18.105	-2.847	-11.719	0.000	-14.566
Romania	-20.874	-2.672	70.291	-83.187	-8.075	2.770	8.941	2.821	-7.045	4.717	0.099	-2.046	0.000	-1.947
Slovakia	-5.114	1.003	43.044	-43.144	-3.422	-2.595	-5.686	3.002	0.895	-1.789	0.651	-1.457	0.000	-0.806

Slovenia	3.746	0.062	10.975	-6.594	-0.440	-0.257	-0.897	0.516	0.107	-0.274	0.067	-0.050	0.000	0.017
Spain	151.480	4.791	140.343	-4.139	28.324	-17.839	-54.449	-26.055	51.471	-29.033	-2.047	13.239	0.001	11.194
Sweden	-4.245	1.811	31.484	-33.061	-3.158	-1.321	0.075	-0.608	0.439	-0.095	-0.078	-1.148	0.000	-1.227
Switzerland	0.276	3.062	9.082	-11.058	-0.550	-0.261	-0.116	-1.688	1.379	-0.425	0.333	-0.169	0.000	0.164
Turkey	136.198	36.319	70.165	17.673	26.647	-14.606	1.264	-62.505	50.954	-10.287	-0.711	-3.606	-0.002	-4.320
United Kingdom	-17.281	27.493	273.335	-307.422	14.865	-25.552	-61.428	-16.639	48.426	-29.641	0.085	4.004	0.000	4.089
Total	356.837	156.934	1948.759	-1577.004	-5.529	-166.323	-259.239	-180.574	292.977	-146.836	21.102	-40.595	0.005	-19.488
World total	7361.384	2163.019	15435.582	-9350.248	-249.757	-637.212	-199.300	-952.550	861.237	-290.613	3.090	-346.487	-3.202	-346.599

Note: The figures '0.000' in the table indicate very small values.

while in 63% cases (79% of Europe, 75% of Eurasia, 70% of Middle East, 59% each of Africa and Asia & Oceania, 54% of Central & South America and 50% of North America), there were negative variances of emission intensity. 10% countries (21% of Central & South America, 16% of Asia & Oceania and 12% of Africa) showed positive variances for all of the factors.

Among the countries which lowered their emissions, in 79% of the cases (67% of Eurasia, 38% of Europe, 4% of Central & South America, 3% of Asia & Oceania and 2% of Africa) and in 64% of the cases (24% of Europe, 17% of Eurasia, 12% of Africa, 9% of Asia & Oceania and 4% of Central & South America), the income and population variances were positive respectively, while in 43% of the cases (24% of Europe, 17% of Eurasia, 4% of Central & South America, 3% of Asia & Oceania and 2% of Africa) both the variances were positive. The energy intensity variance was positive only in Zimbabwe, the substitution variance was positive in cases of United Kingdom, Lithuania, Bulgaria, Cuba and Belarus, while emission intensity variance was positive in 36% of the cases (14% of Europe, 9% of Asia & Oceania, 8% of Eurasia and 5% of Africa). For these emission reducing countries taken together, in aggregate, only income variance was positive, that was outweighed to the extent of 128% by all the other variances, out of which, 107% was offset by energy intensity alone, while 8%, 8% and 4% were neutralized by negative emission intensity, substitution and population variances respectively. A noticeable fact is that except Zimbabwe and Congo (Kinshasa), in all the other emission-reducing countries, the energy intensity variance was the dominating factor in reducing emission, and in most (64%) of the cases, the effect completely offset the positive variances of income and population taken together, while in 11% of the cases it was substitution effect that offset the positive variances.

82% of the countries experienced positive growth in emission, of which 11% (15% of Africa, 13% of Asia & Oceania, 10% of Middle East, 8% of Eurasia and 7% of Central & South America) had negative income variance and in 5% of the cases (18% of Central & South America and 17% of Eurasia) population variance remained negative. In 42% of the countries (68% of Central & South America, 47% of Asia & Oceania, 40% of Middle East, 37% of Africa, and 3% of Europe), energy intensity variance, in 51% of the cases (50% each of North America and Middle East, 46% of Central & South America, 41% each of Africa and Asia & Oceania, 38% of Europe and 33% of Eurasia) substitution variance and in 37% of the cases (50% of North America, 46% of Central & South America, 37% of Africa, 31% of Asia & Oceania, 30% of Middle East, 17% of Eurasia and 7% of Europe) emission intensity variance remained positive. At their aggregate level, the positive income variance was nearly six times more than that of population. However, the total positive variances of the two were offset to the extent of 44% by energy intensity variance and 3% by emission intensity variance, while the effect of substitution variance was insignificant (-0.3%). In 54% of the countries (all of North America, 55% of Europe, 50% of Middle East, 49% of Africa, 38% of Asia & Oceania, 33% of Eurasia and 29% of Central & South America) the negative variance of energy intensity was dominating, in 4% of the cases (11% of Central & South America, 3% of Asia & Oceania and 2% of Africa) the negative substitution variance was dominating, while in 20% of the countries (40% of Middle East, 25% each of Asia & Oceania and Central & South America, 12% of Africa and 7% of Europe) emission intensity variance remained the dominating one. In 8% of the countries (14% of Central & South America, 10% of Africa and 6% of Asia & Oceania) all the variances were positive. In 34% of the cases (50% of Middle East, 49% of Africa, 36% of Central & South America, 25% of Asia & Oceania, and 8% of Eurasia) positive population variance dominated over that of income variance. The notable fact is that in 22% of the countries (36% of Central & South America, 25% of Asia & Oceania, 22% of

Africa and 10% of Middle East) the positive variances of energy intensity, substitution and emission intensity taken together dominated that of population and income.

The decomposition of emission intensity variance shows that 42% of the sample countries (76% of Europe, 58% of Eurasia, 50% of Middle East, 36% of Central & South America, 25% of North America, 31% of Asia & Oceania and 27% of Africa) had negative fuel mix variance, while for 27% of the countries (50% of North America, 42% of Eurasia, 41% of Asia & Oceania, 40% of Middle East, 24% of Europe, 17% of Africa and 14% of Central & South America), the variance was positive. The remaining countries had no change in fuel mix. 61% of the countries (75% each of Eurasia and North America, 70% of Middle East, 66% of Asia & Oceania, 62% of Europe, 56% of Africa and 50% of Central & South America) had negative yield variance, while for the remaining, the variance was positive. In 29% of the cases (48% of Europe, 42% of Eurasia, 40% of Middle East, 17% of Africa, 25% each of Asia & Oceania and Central & South America and 25% of North America), both the variances were negative, while they were positive in 10% of the cases (25% of North America, 20% of Middle East, 13% of Asia & Oceania, 11% of Central & South America, 10% of Europe, 8% of Eurasia and 5% of Africa). At the aggregate level, the contributions of fuel mix and fuel yield to the emission intensity variance was 46% and 54% respectively.

Among the countries with negative emission intensity variance, apart from the ones having negative variances for both fuel mix and fuel yield, in 15% of the cases (24% of Europe, 17% of Eurasia, 10% of Middle East, 7% of Africa, 3% of Asia & Oceania and 4% of Central & South America), higher negative fuel mix variance more than offset the positive fuel yield variance, while in 23% of the cases (27% of Africa, 25% of North America, 21% of Central & South America, 13% of Asia & Oceania and 10% of Middle East), negative fuel yield variance was accompanied by zero fuel mix variance and in 15% of the cases (19% of Asia & Oceania, 17% of Eurasia, 10% of Middle East, 7% each of Africa and Europe and 4% of Central & South America), negative fuel yield variance exceeded the positive fuel mix variance. Among the countries with positive emission intensity variance, apart from those having both the variances positive, in 11% of the cases (25% North America, 17% of Eurasia, 10% of Middle East, 9% of Asia & Oceania, 7% of Europe and 5% of Africa), positive fuel mix variance exceeded the negative fuel yield variance, while in 25% of the cases (29% each of Africa and Central & South America, and 16% of Asia & Oceania), positive fuel yield variance was accompanied by zero fuel mix variance and in 5% of the cases (7% of Central & South America, 3% each of Asia & Oceania and Europe, and 2% of Africa), positive fuel yield variance was greater than the negative fuel mix variance.

33% of the sample countries (66% of Europe, 58% of Eurasia, 27% of Africa, 25% of North America, 15% of Central & South America, 19% of Asia & Oceania and 20% of Middle East) had negative coal mix variance and in 29% of the countries (50% each of Asia & Oceania and North America, 42% of Eurasia, 34% of Europe, 20% of Middle East, 18% of Central & South America and 12% of Africa), the variance was positive, while others had no change in coal mix. 42% of the countries (67% of Eurasia, 60% of Middle East, 52% of Europe, 50% of Asia & Oceania, 36% of Central & South America, 25% of North America and 22% of Africa) had negative petroleum mix variance while in 28% of the cases (50% of North America, 48% of Europe, 33% of Eurasia, 30% of Middle East, 22% each of Africa and Asia & Oceania and 14% of Central & South America), the variance was positive, while others had no change in petroleum mix. 16% of the countries (50% of North America, 33% of Eurasia, 30% of Middle East, 28% of Europe, 13% of Asia & Oceania, 7% of Africa and 4% of Central & South America) had negative dry natural gas mix variance and in 38% of the countries (69% of Europe, 67% of Eurasia, 50% of Middle East, 38% of Asia & Oceania, 32% of Central & South America, 25% of North

America and 10% of Africa,) the variance was positive, others experiencing no change. 31% of the countries (56% of Africa, 50% of Central & South America, 28% of Asia & Oceania, 25% of North America and 10% of Middle East) had no change in their fuel mix variances.

Among the countries with negative fuel mix variances, 8% of them (25% of North America, 7% of Central & South America, 13% of Asia & Oceania, 14% of Europe, 8% of Eurasia and 10% of Middle East) had positive variances of both coal and dry natural gas, the combined effects of which were more than offset by the negative mix variance of petroleum. In 6% of the countries (28% of Europe and 6% of Asia & Oceania) mix variances of both petroleum and dry natural gas were positive, which was outweighed by the negative variance of coal. In 8% of the cases (17% of Africa, 7% of Central & South America, 6% of Asia & Oceania and 3% of Europe) the positive mix variance of petroleum with zero mix variance of dry natural gas had been more than offset by negative mix variance of coal, and in 4% of the cases (30% of Middle East, 11% of Central & South America and 3% of Asia & Oceania) the positive mix variance of dry natural gas with zero mix variance of coal had been more than offset by negative mix variance of petroleum. In the remaining cases, negative mix variances of both coal and petroleum exceeded the positive mix variance of dry natural gas.

On the other hand, in the countries with positive fuel mix variance, in 6% of the cases (25% each of Eurasia and North America, 10% of Europe, 6% of Asia & Oceania and 4% of Central & South America) both coal and petroleum mix variances and in 4% of the cases (13% of Asia & Oceania, 8% of Eurasia and 4% of Central & South America) both coal and dry natural gas mix variances were positive. In 7% of the cases (16% of Asia & Oceania, 10% each of Africa and Middle East and 4% of Central & South America) the positive coal mix variance, accompanied by zero mix variance in dry natural gas had exceeded the negative mix variance of petroleum and in 3% of the cases (10% of Europe, 3% of Asia & Oceania and 2% of Africa) the positive coal mix variance had outweighed the negative mix variances of both petroleum and dry natural gas. In the remaining cases, only petroleum mix variance remained positive, of which, in Jamaica, the negative mix variance of coal, in cases of Papua New Guinea, Georgia, Netherlands and the United States, the negative mix variances of both coal and dry natural gas, and in the cases of Iraq, Kuwait, Angola, Bahrain and Gabon, the only negative mix variance of dry natural gas had been outweighed by the positive petroleum mix variance.

At the aggregate level of the countries with negative fuel mix variance, only petroleum and coal mix variances were negative, and their respective contributions were about 59% and 41% of the total negative value, while the effect was offset by nearly 69% by positive dry natural gas mix variance. In the negative fuel mix variance, coal remained dominant in 19% of the cases (48% of Europe, 20% of Africa, 13% of Asia & Oceania and 11% of Central & South America), while in the remaining cases petroleum was the dominating one. At the aggregate level of the countries with positive fuel mix variance, coal and dry natural gas have contributed about 95% and 5% respectively to the positive value, but were offset by 71% due to negative petroleum mix variance. In the positive fuel mix variance, coal was dominant in 14% of the cases (28% of Asia & Oceania, 14% of Europe, 12% of Africa, 10% of Middle East, 8% of Eurasia and 7% of Central & South America), dry natural gas only in South Korea and petroleum in the remaining cases.

Among the sample countries, 25% (42% of Eurasia, 41% of Europe, 34% of Asia & Oceania, 20% of Africa and 11% of Central & South America) had negative yield variance of coal, while for 26% of the cases (75% of North America, 55% of Europe, 42% of Eurasia, 25% of Asia & Oceania, 21% of Central & South America and 5% of Africa) the variance was positive, and the remaining countries had no change

in the yield. 38% of the countries (50% of Central & South America, 46% of Africa, 44% of Asia & Oceania, 30% of Middle East, 25% each of Eurasia and North America and 21% of Europe) had positive yield variance of petroleum, while in the remaining countries the variance was negative. 26% of the countries (45% of Europe, 40% of Middle East, 33% of Eurasia, 25% each of Asia & Oceania and North America, 21% of Central & South America and 10% of Africa) had negative yield variance of dry natural gas, for 28% of the cases (67% of Eurasia, 52% of Europe, 50% of North America, 40% of Middle East, 25% of Asia & Oceania, 14% of Central & South America and 7% of Africa) the variance was positive, and the remaining countries had no change in the yield.

Among the countries with negative fuel yield variance, in 9% of the cases (10% of Europe, 8% of Eurasia, 6% of Asia & Oceania, 5% of Africa and 4% of Central & South America), yield variances for all the fuels were negative. The negative yield variances of both coal and petroleum in 21% of the cases (25% of Eurasia, 24% of Europe, 16% of Asia & Oceania, 10% of Middle East, 75% of Africa and Central & South America), of both coal and dry natural gas in 3% of the cases (6% of Asia & Oceania and 3% of Europe), of both petroleum and dry natural gas in 15% of the cases (20% of Middle East, 13% of Asia & Oceania, 10% of Europe, 8% of Eurasia, 7% of Central & South America and 5% of Africa), of only coal in cases of Laos and Swaziland, and of only petroleum in the remaining cases, were the primary reason behind the negative fuel yield variance. On the other hand, out of the countries with positive fuel yield variance, in the cases of Australia, Venezuela and Netherlands, all the yield variances remained positive. The positive yield variance of both coal and petroleum in 16% of the cases (25% of North America, 20% of Middle East, 10% of Europe, 85% of Eurasia, 5% of Africa and 3% of Asia & Oceania), of both petroleum and dry natural gas in 10% of the cases (9% of Asia & Oceania, 8% of Eurasia, 4% of Central & South America and 3% of Europe), of only coal in 10% of the cases (21% of Europe), and of only petroleum in the remaining cases resulted in the positive fuel yield variance.

At the aggregate level, petroleum and coal accounted for about 92% and 8% respectively, while dry natural gas had very insignificant contribution in countries with negative fuel yield variance. Among these countries, only in 8% cases, (14% of Europe, 9% of Asia & Oceania and 2% of Africa) coal yield variance remained dominant, while in others, petroleum yield variance was dominant. At the aggregate level of the countries with positive fuel yield variance, petroleum and coal yield variances accounted for about 58% and 42% respectively, while dry natural gas yield variance accounted for –4% of the total positive variance. Within these countries, only in 13% of the cases (24% of Europe and 3% of Asia & Oceania) coal yield variance remained dominant, while in the others petroleum yield variance was dominant.

Considering the aggregate of 5% of the countries (25% of Eurasia, 14% of Europe and 3% of Asia & Oceania) with highest emission reduction (accounting for about 88% of the aggregate reduction), it is found that the only positive variance has been that of income. The population variance offset the positive variance by about 6%, substitution variance by 8% and emission intensity variance by about 9% and energy intensity variance alone by nearly 107%. In all the cases, energy intensity variance remained the dominant one. On the other hand, at their aggregate level of the 5% highest emission increasing countries (25% of North America, 16% of Asia & Oceania, 10% of Middle East and 3% of Europe) contributing nearly 75% of the aggregate increase, both income and population variances had been considerably positive, with the former being eight times more than the latter. Although negative energy intensity variance offset the combined positive effects of the two by nearly 47%, the offsetting effect of negative emission intensity and substitution variances were only by about

3% and 1% respectively. In all the cases, positive income variance remained dominating in raising emission, while energy intensity variance dominated in pulling down the effect. The notable fact is that for the top 5% emission reducing countries, in aggregate, fuel mix variance dominated fuel yield variance, while for the top 5% emission increasing countries, fuel yield variance dominated the fuel mix variance.

5. Discussion

The findings confirm the common contention that both rising population and per capita GDP are the driving forces in perpetuating emission, whereas reductions in energy and emission intensities, and substitution of fossil fuel by non-emitting ones have 'pull' effects on emission. However, contrary to the previous studies,⁸ we find that in aggregate, the effect of rise in per capita GDP has been about seven times more than that of population. Declining energy intensity of GDP accounted for neutralizing more than half of the 'push' effect due to increases in income and population, while emission intensity and substitution, although not very remarkable at the aggregate level, did have some role to arrest the growth of emission.

Even with the overwhelming importance of per capita GDP in intensifying emission, a large number of countries of Eurasia and Europe had been successful in reducing the absolute magnitude of their emission despite growing income. This seems to have been possible mainly due to the dominant role of improvement in energy efficiency. In most of the cases, it was sufficient to neutralize the emission increasing forces. Nonetheless, for the emission reducing countries, lowering of emission intensity of energy had significant contribution in combating the potential growth in emission, both in cases when energy intensity was high and in reinforcing the low energy intensity. On the other hand, in countries with higher growth in emission, the reducing forces could only offset less than half of the rising emission. However, we also identify some countries where both income and population effects were either negative or very insignificant, but rising emission and energy intensities, along with an increasing rate of use of fossil fuel in total primary energy have been the major players in escalating emission.

Although reduction of energy intensity has been the most successful tool in ameliorating the push effect of rising income and population, the extent of reduction is constrained by the modern energy-intensive production and transportation. Therefore, instead of overtly relying on it, the opportunities of reduction of emission through the other two factors should be explored. We find considerable prospect of reduction in emission through substitution effect. Substitution of a single quadrillion Btu of coal, petroleum and dry natural gas by non-polluting primary energy, on an average, can reduce emission respectively by 94.37, 64.59 and 52.84 million metric tons. Even in cases when substitution of fossil fuels with that of non-polluting ones is not possible, inter-fuel substitution - between coal and petroleum, coal and dry natural gas, and petroleum and dry natural gas, on average, can save, 29.78, 41.52 and 11.78 million metric tons of emission per quadrillion Btu respectively.

There exists considerable variation in the emission intensities of each fossil fuel in different countries, indicating the scope for

⁸ Shi [13] found that 1% growths in population and per capita GDP brings about a rise in emission by 1.12% and 1% respectively, whereas the corresponding figures were 0.55% and 0.42% in Martínez-Zarzoso [35]. In our findings the figures are 0.57% and 1.13% respectively. Again the World Bank [29] study shows that population increases were associated with an effect almost half as large as GDP per capita in raising emission.

lowering them in several countries. The emission intensity in million metric tons per quadrillion Btu of coal ranges from 82.64 in Egypt to 179.58 in Netherlands, that of petroleum being 49.26 in South Korea and 75.41 in Panama, and that of dry natural gas being 52.13 in the USA and 53.1 in Morocco. The reason behind the huge disparities may be due to differences in the quality of fuel and/or the level of technologies used.

However, we find that only about one-third of the countries have employed fuel substitution in combating rising emission, but their performances have not been impressive. Decomposing the emission intensity effect reveals that both changes in the structural composition of fuel and changes in their emission intensities had important roles, with the latter having more contribution than the former. The overall trend is more towards substitution of petroleum by dry natural gas and reduction in its emission intensity, while there has been very little substitution of coal and its emission intensity has also gone up.

6. Conclusion

In the context of the alarming surge in world emission in recent years, particularly by the emerging economies and a number of high-income ones, a pertinent issue is whether there is a trade off between economic growth and low emission. With the aim to address this vital issue, this paper develops a decomposition method based on variance analysis; uses it to decompose energy-related emission to identify its major perpetrators and explores possible mechanisms of arresting emission.

From the findings, it is observed that although rising income and population are the most potent catalysts, they are neither necessary nor sufficient in escalating emission. There exist possibilities to reduce emission even with rising income and natural growth in population. Evidently, it is not only the growing population and penchant for economic growth in the highest emitting countries that are to be blamed; the pattern of energy use has a crucial role as well. Therefore it is imperative to develop appropriate energy management to be able to counteract the 'push' effect on emission due to growth. Emphasis should be given on substitution of emitting fuels by non-emitting ones as far as practicable; in cases where it is not feasible, policies may be targeted towards substituting more emitting fuels by less emitting ones, and reducing emission intensities of each fuel through technological development. Management accounting practice and control from the corporate to the national level is likely to be effective in this regard. The phenomenon of energy management may include variance analysis of present performance against the past to comprehend the causal relationships. The analysis can be an effective tool in identifying the areas where the performances are poor compared to other countries and whether the performances can be improved and how. In this regard, some other management accounting tools like zero base budgeting and sensitivity analysis can be effectively used. If adequate management control over energy use is achieved, it can fairly be expected that economic growth can go hand in hand with less emission, which may pave the path towards sustainable development.

7. Scope for further research

Since a paper cannot address all relevant issues due to limitations with respect to length, the present paper, aiming at decomposition analysis of the change in global CO₂ emission, emphasises only on its prime determinants (identified in the literature) with particular focus on emission intensity effect. However, we trace some of the other factors that play considerable role in emission

change of a country and give an outline to deal with them, that may be taken up for future study.

First, in open economies, the production and resulting emission may not be associated solely with economic growth and development in that particular country. Thus emission of a country is often influenced by factors outside the national boundaries. To analyse the impact of external factors, in addition to domestic factors, the model may be redesigned as $CO_2 \equiv (CO_2/FEN) \times (FEN/PEN) \times (PEN/GDP) \times (GDP/GNP) \times (GNP/POP) \times (POP)$, where (GDP/GNP) is the proportion of gross national product (GNP) produced domestically and (GNP/POP) is the per capital GNP. Secondly, different sources of emission may have different nature of contributions. To examine the relative importance of different emission sources, analogous to Eq. (14), the GDP may be broken down into its components and Y_i be replaced by $\sum Y_{ji}$, where j signifies different components of GDP like consumption, investment, government spending and net exports. Thirdly, structural composition of GDP has significant role in regulating energy consumption and resulting emission. To analyse the significance of changes in sectoral composition, if any, on emission, analogous to Eq. (14), E_i may be replaced by $\sum E_{ji}S_{ji}$, where E_{ji} denotes energy intensity of sector j ; S_{ji} is the proportion of GDP contributed by sector j . Fourthly, different countries may differ in emission at similar conditions due to their level of capital and technology. To study the significance of cross-section variation and to have a benchmark analysis, the emission and its factors of a particular country (X^*) have to be taken as the 'standard' and variations of other countries (X_i) have to be measured accordingly. In the similar way, other factors that affect emission of a country may be incorporated for their relative impact analysis.

Moreover, effects of non-technical factors are also reflected in emission intensity and energy intensity. The change in these two factors can largely be explained by changes in composition of fuel, structural change in economic activities and improvement in technology. However, some changes may not be captured by these technical factors. The unexplained changes may be attributed to changes in non-technical factors like social, cultural, educational, behavioural, international influence, etc. A detailed analysis of these intensities can provide the relative impacts of the non-technical factors.

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